U.S. Department of Justice
Office of Justice Programs
National Institute of Justice

National Institute of Justice

Law Enforcement and Corrections Standards and Testing Program

Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders

NIJ Guide 100-00

Volume I
June 2000

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SECTION 2.0
INTRODUCTION TO CHEMICAL AGENTS AND TOXIC INDUSTRIAL MATERIALS

The purpose of this section is to provide a description of chemical agents (CAs) and toxic industrial materials (TIMs). Section 2.1 provides the discussion of chemical agents and section 2.2 provides the discussion of TIMs.

2.1 Chemical Agents

Chemical agents are chemical substances that are intended for use in warfare or terrorist activities to kill, seriously injure, or seriously incapacitate people through their physiological effects. A chemical agent attacks the organs of the human body in such a way that it prevents those organs from functioning normally. The results are usually disabling or even fatal.

The most common chemical agents are the nerve agents, GA (Tabun), GB (Sarin), GD (Soman), GF, and VX; the blister agents, HD (sulfur mustard) and HN (nitrogen mustard); and the arsenical vesicants, L (Lewisite). Other toxic chemicals such as hydrogen cyanide (characterized as a chemical blood agent by the military) are included as TIMs under Section 2.2 of this guide.

2.1.1 Nerve Agents

This section provides an overview of nerve agents. A discussion of their physical and chemical properties, their routes of entry, and descriptions of symptoms is also provided.

2.1.1.1 Overview

Among lethal chemical agents, the nerve agents have had an entirely dominant role since World War II. Nerve agents acquired their name because they affect the transmission of impulses in the nervous system. All nerve agents belong to the chemical group of organo-phosphorus compounds; many common herbicides and pesticides also belong to this chemical group. Nerve agents are stable, easily dispersed, highly toxic, and have rapid effects when absorbed both through the skin and the respiratory system. Nerve agents can be manufactured by means of fairly simple chemical techniques. The raw materials are inexpensive but some are subject to the controls of the Chemical Weapons Convention and the Australia Group Agreement.

2.1.1.2 Physical and Chemical Properties

The nerve agents considered in this guide are:

- GA: A low volatility persistent chemical agent that is taken up through skin contact and inhalation of the substance as a gas or aerosol. Volatility refers to a substance's ability to become a vapor at relatively low temperatures. A highly volatile (non-persistent) substance poses a greater respiratory hazard than a less volatile (persistent) substance.

- GB: A volatile non-persistent chemical agent mainly taken up through inhalation.
- GD: A moderately volatile chemical agent that can be taken up by inhalation or skin contact.
- GF: A low volatility persistent chemical agent that is taken up through skin contact and inhalation of the substance either as a gas or aerosol.
- VX: A low volatility persistent chemical agent that can remain on material, equipment, and terrain for long periods. Uptake is mainly through the skin but also through inhalation of the substance as a gas or aerosol.

Nerve agents in the pure state are colorless liquids. Their volatility varies widely. The consistency of VX may be likened to motor oil and is therefore classified as belonging to the group of persistent chemical agents. Its effect is mainly through direct contact with the skin. GB is at the opposite extreme; being an easily volatile liquid (comparable with, e.g., water), it is mainly taken up through the respiratory organs. The volatilities of GD, GA, and GF are between those of GB and VX. Table 2-1 lists the common nerve agents and some of their properties. Water is included in the table as a reference point for the nerve agents.

Table 2-1. Physical Properties of Common Nerve Agents

Property	GA	GB	GD	GF	VX	Water
Molecular weight	162.3	140.1	182.2	180.2	267.4	18
Density, g/cm^3*	1.073	1.089	1.022	1.120	1.008	1
Boiling-point, °F	464	316	388	462	568	212
Melting-point, °F	18	-69	-44	-22	< -60	32
Vapor pressure, mm Hg *	0.07	2.9	0.4	0.06	0.0007	23.756
Volatility, mg/m^3 *	610	22,000	3,900	600	10.5	23,010
Solubility in water, % *	10	Miscible with water	2	~2	Slightly	NA

* at 77 °F

2.1.1.3 Route of Entry

Nerve agents, either as a gas, aerosol, or liquid, enter the body through inhalation or through the skin. Poisoning may also occur through consumption of liquids or foods contaminated with nerve agents.

The route of entry also influences the symptoms developed and, to some extent, the sequence of the different symptoms. Generally, the poisoning works fastest when the agent is absorbed through the respiratory system rather than other routes because the lungs contain numerous blood vessels and the inhaled nerve agent can rapidly diffuse into the blood circulation and thus reach the target organs. Among these organs, the respiratory system is one of the most important. If a person is exposed to a high concentration of nerve agent, e.g., 200 mg sarin/m^3, death may occur within a couple of minutes.

The poisoning works slower when the agent is absorbed through the skin. Because nerve agents are somewhat fat-soluble, they can easily penetrate the outer layers of the skin, but it takes longer for the poison to reach the deeper blood vessels. Consequently, the first symptoms do not occur until 20 to 30 minutes after the initial exposure but subsequently, the poisoning process may be rapid if the total dose of nerve agent is high.

2.1.1.4 Symptoms

When exposed to a low dose of nerve agent, sufficient to cause minor poisoning, the victim experiences characteristic symptoms such as increased production of saliva, a runny nose, and a feeling of pressure on the chest. The pupil of the eye becomes contracted (miosis) which impairs night-vision. In addition, the capacity of the eye to change focal length is reduced and short-range vision deteriorates causing the victim to feel pain when trying to focus on nearby objects. This is accompanied by headache. Less specific symptoms are tiredness, slurred speech, hallucinations and nausea.

Exposure to a higher dose leads to more dramatic developments and symptoms are more pronounced. Bronchoconstriction and secretion of mucus in the respiratory system leads to difficulty in breathing and to coughing. Discomfort in the gastrointestinal tract may develop into cramping and vomiting, and there may be involuntary discharge of urine and defecation. There may be excessive salivating, tearing, and sweating. If the poisoning is moderate, typical symptoms affecting the skeletal muscles may be muscular weakness, local tremors, or convulsions.

When exposed to a high dose of nerve agent, the muscular symptoms are more pronounced and the victim may suffer convulsions and lose consciousness. The poisoning process may be so rapid that symptoms mentioned earlier may never have time to develop.

Nerve agents affect the respiratory muscles causing muscular paralysis. Nerve agents also affect the respiratory center of the central nervous system. The combination of these two effects is the direct cause of death. Consequently, death caused by nerve agents is similar to death by suffocation.

2.1.2 Blister Agents (Vesicants)

This section provides an overview of blister agents. A discussion of their physical and chemical properties, their routes of entry, and descriptions of symptoms is also provided.

2.1.2.1 Overview

There are two major families of blister agents (vesicants): sulfur mustard (HD) and nitrogen mustard (HN), and the arsenical vesicants (L). All blister agents are persistent and may be employed in the form of colorless gases and liquids. They burn and blister the skin or any other part of the body they contact. Blister agents are likely to be used to produce casualties rather than to kill, although exposure to such agents can be fatal.

2.1.2.2 Physical and Chemical Properties

In its pure state, mustard agent is colorless and almost odorless. It earned its name as a result of an early production method that resulted in an impure product with a mustard-like smell. Mustard agent is also claimed to have a characteristic odor similar to rotten onions. However, the sense of smell is dulled after only a few breaths so that the odor can no longer be distinguished. In addition, mustard agent can cause injury to the respiratory system in concentrations that are so low that the human sense of smell cannot distinguish them.

At room temperature, mustard agent is a liquid with low volatility and is very stable during storage. Mustard agent can easily be dissolved in most organic solvents but has negligible solubility in water. In aqueous solutions, mustard agent decomposes into non-poisonous products by means of hydrolysis but, since only dissolved mustard agent reacts, the decomposition proceeds very slowly. Oxidants such as chloramine (see page 24 for chloramine action), however, react violently with mustard agent, forming non-poisonous oxidation products. Consequently, these substances are used for the decontamination of mustard agent.

Arsenical vesicants are not as common or as stable as the sulfur or nitrogen mustards. All arsenical vesicants are colorless to brown liquids. They are more volatile than mustard and have fruity to geranium-like odors. These types of vesicants are much more dangerous as liquids than as vapors. Absorption of either vapor or liquid through the skin in adequate dosage may lead to systemic intoxication or death. The physical properties of the most common blister agents are listed in Table 2-2. Water is included in the table as a reference point for the blister agents.

Table 2-2. Physical Properties of Common Blister Agents

Property	HD	HN-1	HN-2	HN-3	L	Water
Molecular weight	159.1	170.1	156.1	204.5	207.4	18
Density, g/cm^3	1.27 at 68°F	1.09 at 77°F	1.15 at 68°F	1.24 at 77°F	1.89 at 68°F	1 at 77°F
Boiling-point, °F	421	381	167 at 15 mm Hg	493	374	212
Freezing-point, °F	58	-61.2	-85	-26.7	64.4 to 32.18	32
Vapor pressure, mm Hg	0.072 at 68°F	0.24 at 77°F	0.29 at 68°F	0.0109 at 77°F	0.394 at 68°F	23.756 at 77°F
Volatility, mg/m^3	610 at 68°F	1520 at 68°F	3580 at 77°F	121 at 77°F	4480 at 68°F	23,010 at 77°F
Solubility in water, %	<1%	Sparingly	Sparingly	Insoluble	Insoluble	NA

2.1.2.3 Route of Entry

Most blister agents are relatively persistent and are readily absorbed by all parts of the body. Poisoning may also occur through consumption of liquids or foods contaminated with blister agents. These agents cause inflammation, blisters, and general destruction of tissues. In the form of gas or liquid, mustard agent attacks the skin, eyes, lungs, and gastro-intestinal tract. Internal organs, mainly blood-generating organs, may also be injured as a result of mustard agent being taken up through the skin or lungs and transported into the body. Since mustard agent gives no immediate symptoms upon contact, a delay of between two and twenty-four hours may occur before pain is felt and the victim becomes aware of what has happened. By then, cell damage has already occurred. The delayed effect is a characteristic of mustard agent.

2.1.2.4 Symptoms

In general, vesicants can penetrate the skin by contact with either liquid or vapor. The latent period for the effects from mustard is usually several hours (the onset of symptoms from vapors is 4 to 6 hours and the onset of symptoms from skin exposure is 2 to 48 hours). There is no latent period for exposure to Lewisite.

Mild symptoms of mustard agent poisoning may include aching eyes with excessive tearing, inflammation of the skin, irritation of the mucous membranes, hoarseness, coughing and sneezing. Normally, these injuries do not require medical treatment.

Severe injuries that are incapacitating and require medical care may involve eye injuries with loss of sight, the formation of blisters on the skin, nausea, vomiting, and diarrhea together with severe difficulty in breathing. Severe damage to the eye may lead to the total loss of vision.

The most pronounced effects on inner organs are injury to the bone marrow, spleen, and lymphatic tissue. This may cause a drastic reduction in the number of white blood cells 5-10 days after exposure, a condition very similar to that after exposure to radiation. This reduction of the immune defense will complicate the already large risk of infection in people with severe skin and lung injuries.

The most common cause of death as a result of mustard agent poisoning is complications after lung injury caused by inhalation of mustard agent. Most of the chronic and late effects from mustard agent poisoning are also caused by lung injuries.

2.2 Toxic Industrial Materials

This section provides a general overview of TIMs as well as a list of the specific TIMs considered in this guide. Since the chemistry of TIMs is so varied, it is not feasible to discuss specific routes of entry and descriptions of symptoms.

Toxic industrial materials, or TIMs, are chemicals other than chemical warfare agents that have harmful effects on humans. TIMs, often referred to as toxic industrial chemicals, or TICs, are used in a variety of settings such as manufacturing facilities, maintenance areas, and general storage areas. While exposure to some of these

chemicals may not be immediately dangerous to life and health (IDLH), these compounds may have extremely serious effects on an individual's health after multiple low-level exposures.

2.2.1 General

A TIM is a *specific type* of industrial chemical i.e., one that has a LCt_{50} value (lethal concentration for 50% of the population multiplied by exposure time) less than 100,000 mg-min/m^3 in any mammalian species and is produced in quantities exceeding 30 tons per year at one production facility. Although they are not as lethal as the highly toxic nerve agents, their ability to make a significant impact on the populace is assumed to be more related to the amount of chemical a terrorist can employ on the target(s) and less related to their lethality. None of these compounds are as highly toxic as the nerve agents, but they are produced in very large quantities (multi-ton) and are readily available; therefore, they pose a far greater threat than chemical agents. For instance, sulfuric acid is not as lethal as the nerve agents, but it is easier to disseminate large quantities of sulfuric acid because of the large amounts that are manufactured and transported every day. It is assumed that a balance is struck between the lethality of a material and the amount of materials produced worldwide. Materials such as the nerve agents are so lethal as to be in a special class of chemicals.

Because TIMs are less lethal than the highly toxic nerve agents, it is more difficult to determine how to rank their potential for use by a terrorist. Physical and chemical properties for TIMs such as ammonia, chlorine, cyanogen chloride, and hydrogen cyanide are presented in Table 2-3. Water is included in the table as a reference point for the TIMs. The physical and chemical properties for the remaining TIMs identified in this guide can be found in <u>*International Task Force 25: Hazard From Industrial Chemicals Final Report*</u>, April 1998. (See detailed reference in Appendix B).

Table 2-3. Physical and Chemical Properties of TIMs

Property	Ammonia	Chlorine	Cyanogen Chloride	Hydrogen Cyanide	Water
Molecular weight	17.03	70.9	61.48	27.02	18
Density, g/cm^3	0.00077 at 77°F	3.214 at 77°F	1.18 at 68°F	0.990 at 68°F	1 at 77°F
Boiling-point, °F	-28	-30	55	78	212
Freezing-point, °F	-108	-150	20	8	32
Vapor pressure, mm Hg at 77°F	7408	5643	1000	742	23.756
Volatility, mg/m^3	6,782,064 at 77°F	21,508,124 at 77°F	2,600,000 at 68°F	1,080,000 at 77°F	23,010 at 77°F
Solubility in water, %	89.9	1.5	Slightly	Highly soluble	NA

2.2.2 TIM Rankings

TIMs are ranked into one of three categories that indicate their relative importance and assist in hazard assessment. Table 2-4 lists the TIMs with respect to their Hazard Index Ranking (High, Medium, or Low Hazard).[2]

2.2.2.1 High Hazard

High Hazard indicates a widely produced, stored or transported TIM that has high toxicity and is easily vaporized.

2.2.2.2 Medium Hazard

Medium Hazard indicates a TIM that may rank high in some categories but lower in others such as number of producers, physical state, or toxicity.

2.2.2.3 Low Hazard

A Low Hazard overall ranking indicates that this TIM is not likely to be a hazard unless specific operational factors indicate otherwise.

[2] International Task Force 25: Hazard From Industrial Chemicals Final Report, April 1998.

Table 2-4. TIMs Listed By Hazard Index

High	Medium	Low
Ammonia	Acetone cyanohydrin	Allyl isothiocyanate
Arsine	Acrolein	Arsenic trichloride
Boron trichloride	Acrylonitrile	Bromine
Boron trifluoride	Allyl alcohol	Bromine chloride
Carbon disulfide	Allylamine	Bromine pentafluoride
Chlorine	Allyl chlorocarbonate	Bromine trifluoride
Diborane	Boron tribromide	Carbonyl fluoride
Ethylene oxide	Carbon monoxide	Chlorine pentafluoride
Fluorine	Carbonyl sulfide	Chlorine trifluoride
Formaldehyde	Chloroacetone	Chloroacetaldehyde
Hydrogen bromide	Chloroacetonitrile	Chloroacetyl chloride
Hydrogen chloride	Chlorosulfonic acid	Crotonaldehyde
Hydrogen cyanide	Diketene	Cyanogen chloride
Hydrogen fluoride	1,2-Dimethylhydrazine	Dimethyl sulfate
Hydrogen sulfide	Ethylene dibromide	Diphenylmethane-4,4'-diisocyanate
Nitric acid, fuming	Hydrogen selenide	Ethyl chloroformate
Phosgene	Methanesulfonyl chloride	Ethyl chlorothioformate
Phosphorus trichloride	Methyl bromide	Ethyl phosphonothioic dichloride
Sulfur dioxide	Methyl chloroformate	Ethyl phosphonic dichloride
Sulfuric acid	Methyl chlorosilane	Ethyleneimine
Tungsten hexafluoride	Methyl hydrazine	Hexachlorocyclopentadiene
	Methyl isocyanate	Hydrogen iodide
	Methyl mercaptan	Iron pentacarbonyl
	Nitrogen dioxide	Isobutyl chloroformate
	Phosphine	Isopropyl chloroformate
	Phosphorus oxychloride	Isopropyl isocyanate
	Phosphorus pentafluoride	n-Butyl chloroformate
	Selenium hexafluoride	n-Butyl isocyanate
	Silicon tetrafluoride	Nitric oxide
	Stibine	n-Propyl chloroformate
	Sulfur trioxide	Parathion
	Sulfuryl chloride	Perchloromethyl mercaptan
	Sulfuryl fluoride	sec-Butyl chloroformate
	Tellurium hexafluoride	tert-Butyl isocyanate
	n-Octyl mercaptan	Tetraethyl lead
	Titanium tetrachloride	Tetraethyl pyropośphate
	Trichloroacetyl chloride	Tetramethyl lead
	Trifluoroacetyl chloride	Toluene 2,4-diisocyanate
		Toluene 2,6-diisocyanate